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"Fast Track" Lunar NTR Systems Assessment for NASA's First Lunar Outpost and its Evolvability to Mars

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"FAST TRACK" LUNAR NTR SYSTEMS ASSESSMENT FOR NASA's FIRST LUNAR OUTPOST AND ITS EVOLVABILITY TO MARS

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Abstract

Integrated systems and missions studies are presented for an evolutionary lunar-to-Mars space transportation system (STS) based on nuclear thermal rocket (NTR) technology. A "standardized" set of engine and stage components are identified and used in a "building block" fashion to configure a variety of piloted and cargo, lunar and Mars vehicles. The reference NTR characteristics include a thrust of 50 thousand pounds force (klbf), specific impulse (I_{sp}) of 900 seconds, and an engine thrust-to-weight ratio of 4.3. For the National Aeronautics and Space Administration's (NASA) First Lunar Outpost (FLO) mission, an expendable NTR stage powered by two such engines can deliver ~96 metric tonnes (t) to trans-lunar injection (TLI) conditions for an initial mass in low Earth orbit (IMLEO) of ~198 t compared to 250 t for a cryogenic chemical system. The stage liquid hydrogen (LH_2) tank has a diameter, length, and capacity of 10 m, 14.5 m and 66 t, respectively. By extending the stage length and LH_2 capacity to ~20 m and 96 t, a single launch Mars cargo vehicle could deliver to an elliptical Mars parking orbit a 63 t Mars excursion vehicle (MEV) with a 45 t surface payload. Three 50 klbf engines and the two standardized LH_2 tanks developed for the lunar and Mars cargo vehicles are used to configure the vehicles supporting piloted Mars missions as early as 2010. The "modular" NTR vehicle approach forms the basis for an efficient STS able to handle the needs of a wide spectrum of lunar and Mars missions.

INTRODUCTION

On July 20, 1989, the 20th anniversary of the Apollo 11 Moon landing, President Bush tasked NASA to undertake a Space Exploration Initiative (SEI) aimed at returning humans to the Moon "to stay" in the next century, followed by a journey to Mars using systems "space tested" in the lunar environment. Initial assessments of the space transportation system elements and infrastructures required to move humans and support equipment (for example, habitats, supplies, and science and exploration equipment) from Earth to the surfaces of the Moon and Mars were outlined in the "90 Day Study Report" (NASA 1989). In a more recent report (Synthesis Group 1991) entitled "America at the Threshold: America's Space Exploration Initiative", the Synthesis Group outlined several different approaches to accomplish the SEI missions.

The Synthesis Group also recommended important technical strategies that affect space transportation systems design. These included use of: (1) a heavy lift launch vehicle (HLLV) to limit on-orbit assembly; (2) a split mission strategy (where cargo and crew fly on separate missions); (3) pre-deployed and verified "turn-key" habitats; (4) chemical and nuclear thermal propulsion for lunar and Mars missions, respectively; (5) direct entry of returning crews to Earth's surface; (6) lunar missions as a "test bed" for Mars, and (7) to the extent possible, common systems for the lunar and Mars missions.

At present, NASA's Exploration Program Office (ExPO) is considering chemical propulsion for an "early return to the Moon", and NTR propulsion for the more demanding Mars missions to follow. Because the time and cost to develop two separate transportation systems could be substantial, the NASA Lewis Research Center (LeRC) has been examining the rationale and benefits of developing a NTR-based lunar STS (Borowski 1991) and then evolving it to Mars mission applications (Borowski et al. 1992) through the use of modular engine and stage components. In addition to enhancing performance, the use of NTR propulsion for lunar missions could provide valuable operational experience while also allowing NASA to make a significant down payment during its initial lunar program on key components of the modular STS needed for the subsequent Mars mission. A modular approach can also enhance mission flexibility and safety, simplify vehicle design and assembly, and reduce development/procurement costs through standardization of the fewest number of components. An accelerated, reduced cost approach to overall lunar/Mars exploration is therefore expected.

NTR PERFORMANCE CHARACTERISTICS

The nuclear thermal rocket represents the next major evolutionary step in propulsion technology. By using a fission reactor, rather than chemical reactants, to provide the heat source, the NTR can use low molecular weight LH_2 as both the reactor coolant and propellant to achieve I_{sp} values nearly twice that of cryogenic chemical rockets at comparable exhaust temperatures.

The feasibility of a hydrogen-cooled, graphite-moderated NTR was demonstrated in the Rover nuclear rocket program (Koenig 1986) begun at Los Alamos in 1955. The promising early results from this effort led to the formation in 1960 of a joint program between NASA and the Atomic Energy Commission (AEC) to develop a Nuclear Engine for Rocket Vehicle Application (NERVA). From 1955 until the program was terminated in 1973, a total of twenty reactors were designed, built and tested at a cost of ~\$1.4 billion. Escalated to 1992 dollars, the Rover/NERVA technology represents an investment of ~\$10 billion.

Performance projections for modern day NERVA-derivative engine systems utilizing both coated particle "graphite" and "composite" fuel forms, and "state-of-the-art" nozzle and turbopump technologies indicate substantial improvements in both I_{sp} and engine thrust-to-weight ratio over the 1972 NERVA reference engine design (see Table 1). Modest increases in chamber temperature, pressure and individual fuel element power output (from ~0.9 megawatts of thermal power (MW_t) to ~1.2 MW_t) have been assumed along with a nozzle area expansion ratio of 200 to 1 and a 110% length optimum contour Rao nozzle. An expander cycle is also baselined with turbine drive gas provided by the propellant that cools the reactor tie-tube support elements. Finally, dual centrifugal turbopumps and an internal radiation shield (comprised of boron-carbide aluminum-titanium hydride (BATH) and lead) are included in the engine weight estimates to provide redundancy, and improve engine reliability and safety.

TABLE 1. Characteristics of NERVA-Type Engines.

Parameters	'72 NERVA*	"State-of-the-art" NERVA Derivatives*					
Engine Flow Cycle	Hot Bleed/Expander	Expander					
Fuel Form	Graphite	Graphite			Composite		
Thrust (klbf)	75	25	50	75	25	50	75
Chamber Temperature (K)	2350	← 2550 →			← 2700 →		
Chamber Pressure (psia)	450	← 785 →			← 785 →		
Nozzle Expansion Ratio	100:1	← 200:1 →			← 200:1 →		
Specific Impulse (sec)	825/845	← 870 →			← 900 →		
Engine Mass (kg)**	11250	3727	4762	6205	3883	5237	6823
Engine Thrust/Weight **	3.0	3.0	4.8	5.5	2.9	4.3	5.0

* Engine masses contain dual turbopump capability for redundancy.
** Includes internal shield but no external disk shield mass.

FIRST LUNAR OUTPOST MISSION/STAGE DESCRIPTION

NASA has spent considerable effort assessing the requirements for returning humans to the Moon. For the FLO, a split mission "lunar campsite" scenario has been adopted (ExPO 1992a). On the initial cargo mission, a pre-integrated, reusable habitat module is delivered intact on a common lander vehicle which performs both lunar orbit insertion and descent. The habitat provides facilities to support a crew of four for 45 Earth days (a lunar day, night, day cycle). Once the operational functions of the outpost have been verified the crew begins their journey to the Moon. On the piloted mission, the habitat module is replaced by a lunar ascent/Earth return stage with the crew module used at mission end for direct Earth entry. Both the cargo and piloted missions are launched separately on a single 250 t-class HLLV.

The main elements of the FLO transportation system are shown in Figure 1. The common lander and its payload are placed on their four day trajectory to the Moon using an expendable TLI stage. The current "reference" TLI stage contains ~133.5 t of liquid oxygen/liquid hydrogen (LOX/LH_2) propellant and uses a single J-2S engine operating at thrust and I_{sp} levels of ~265 klbf and 436 seconds, respectively. The "alternative" NTR stage contains ~66 t of LH_2 propellant and is propelled by two 50 klbf thrust engines operating with a I_{sp} of 900 seconds. After TLI, the spent NTR stage is delivered to a long-lived (~100,000 year) heliocentric orbit via a "trailing edge" lunar gravity assist maneuver.

Key ground rules and assumptions used in determining the characteristics of the lunar NTR TLI stage are summarized in Table 2 which provides details on payload mass, velocity change (ΔV) requirements, primary and auxiliary propulsion, tankage and contingency factors. Figure 2 compares the IMLEO requirements for the FLO mission using both NTR and chemical propulsion systems. Individual data points shown on the single and multi-engine NTR curves indicate representative stage configurations which satisfy a "30 minute limit " on burn time specified in this study to provide additional safety margin. All of the NTR stages considered have lower IMLEO than their chemical engine counterparts. In addition to the single J-2S reference system, a clustered engine

TABLE 2. FLO Mission Ground Rules and Assumptions.

"One Burn" Lunar Scenario		
•TLI Payload	96 t (piloted vehicle & TLI stage adaptor)	
•TLI Maneuver	ΔV	= 3200 m/s + gravity losses
	Initial orbit	= 100 n. mi. circular LEO (185 km)
•NTR System	Propellant	= Cryogenic hydrogen
	Isp	= 900 sec (composite) / 870 sec (graphite)
	External Shield Mass	≈ 60 kg/ klbf thrust
	Burn Duration	≤ 30 minutes
	Flight Performance Reserve	= 1% of usable propellant
	Cooldown (effective)	= 3% of usable propellant
	Residual	= 1.5% of total tank capacity
•RCS System	Propellant	= Hydrazine
	Isp	= 237 sec
	TLI burnout ΔV	= 60 m/s (30 m/s for trailing edge lunar flyby)
•Tankage	Material	= 2219-T87 Al
	Geometry	= 10 m diameter cylindrical tank with $\sqrt{2}/2$ domes
	Insulation	= 2 inch MLI + micrometeoroid shield (3.97 kg/m^2)
	Boiloff	= 12.40 kg / day
•Contingency	Engine & external shields	= 15%
	All other dry masses	= 10%

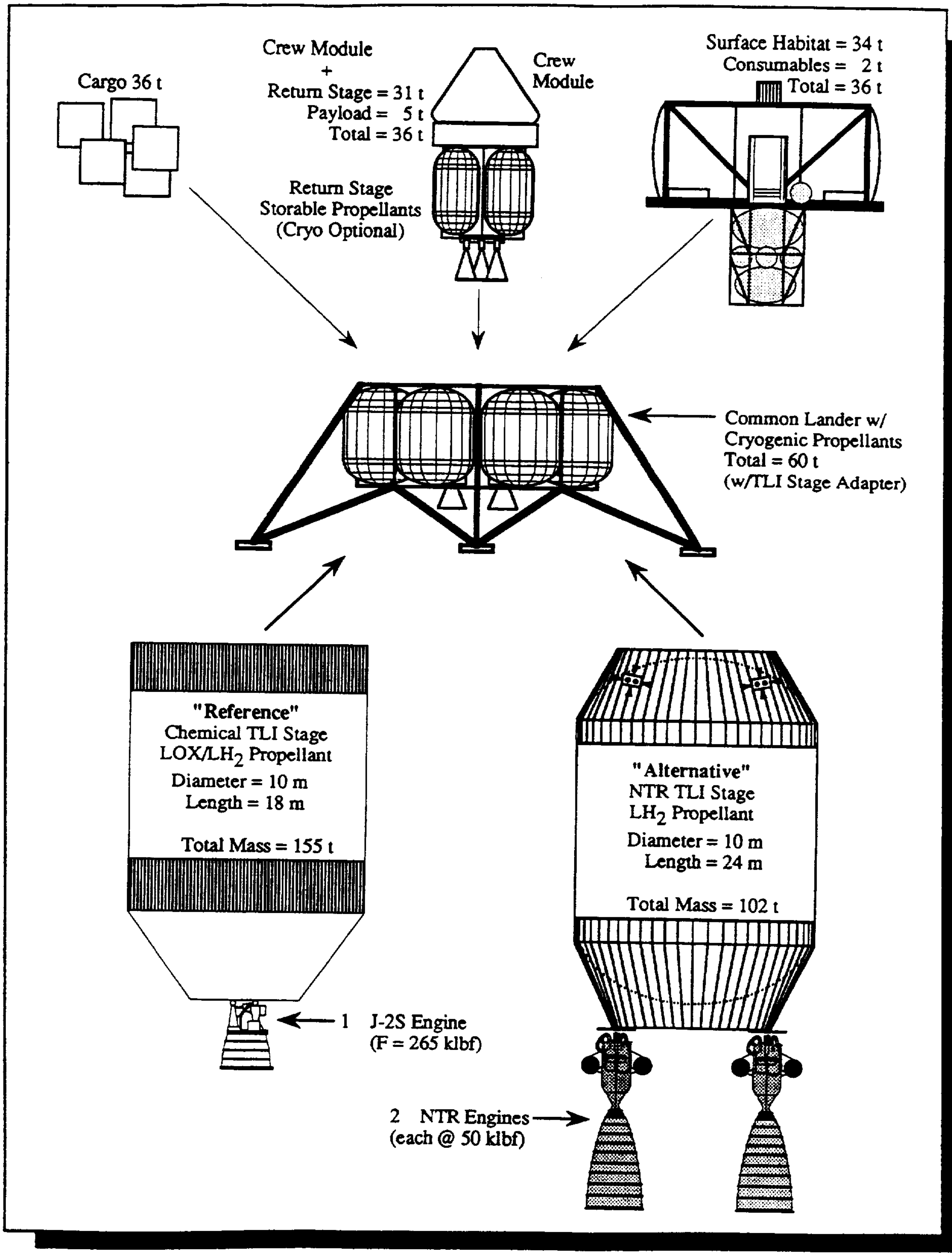


FIGURE 1. FLO Transportation System Elements.

configuration using five RL-10 A-4 engines (but delivering only 80 t of payload) is also shown for comparison. Figure 2 shows quite dramatically that NTR propulsion can enhance the performance capability for the FLO mission. Dimensions and mass characteristics for a reference NTR TLI stage are shown in Figure 3.

MARS MISSION SCENARIOS/VEHICLE DESCRIPTIONS

The ExPO, in conjunction with the NASA centers, is presently assessing the requirements for supporting a piloted mission to Mars as early as 2010 using a split "fast conjunction"-class mission profile (Joosten 1991). With this strategy, cargo would first be transported to Mars by a cargo vehicle(s) taking a slow, minimum energy trajectory to Mars. The piloted vehicle would travel to Mars on a faster, higher energy direct trajectory after receiving confirmation that the cargo vehicle(s) had arrived safely in Mars orbit. By employing a "fast transit time" strategy, it is thought that crew health hazards resulting from long term exposure to weightlessness and space radiation can be minimized. The "fast conjunction" option also maximizes the exploration time at Mars.

Three basic split/sprint mission modes are available for consideration (ExPO 1992b). In the "All-Up" mode, the piloted transfer vehicle (PTV) carries its own Mars excursion vehicle (MEV) and all of the propellant required for the fast-return transit to Earth. The corresponding cargo transfer vehicle (CTV) carries only an autonomous lander outfitted with the necessary supplies to support the surface mission. In the "No MEV" mode, the PTV carries only its return propellant and lands on Mars with a MEV carried on the CTV. A rendezvous in Mars orbit is therefore

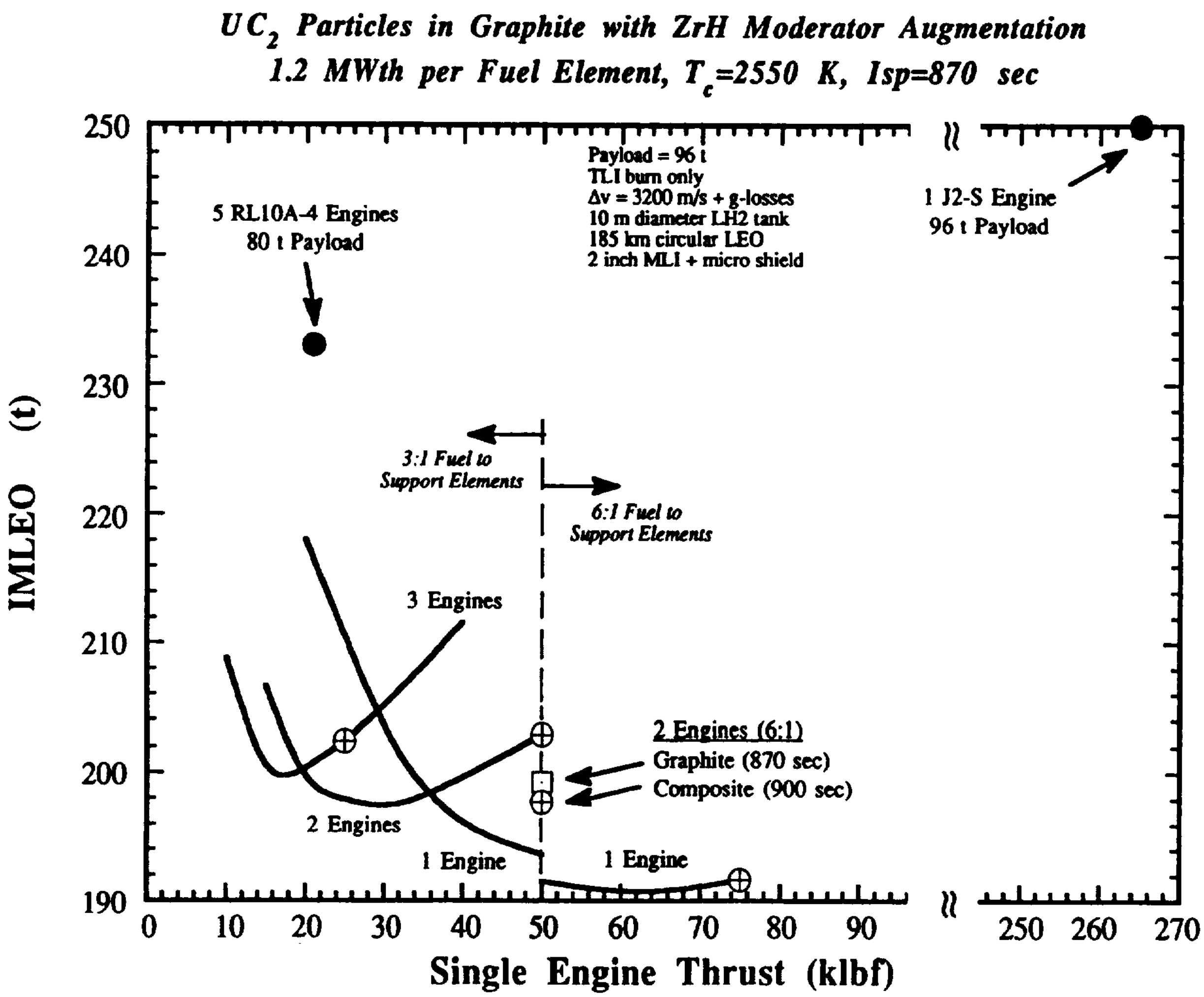
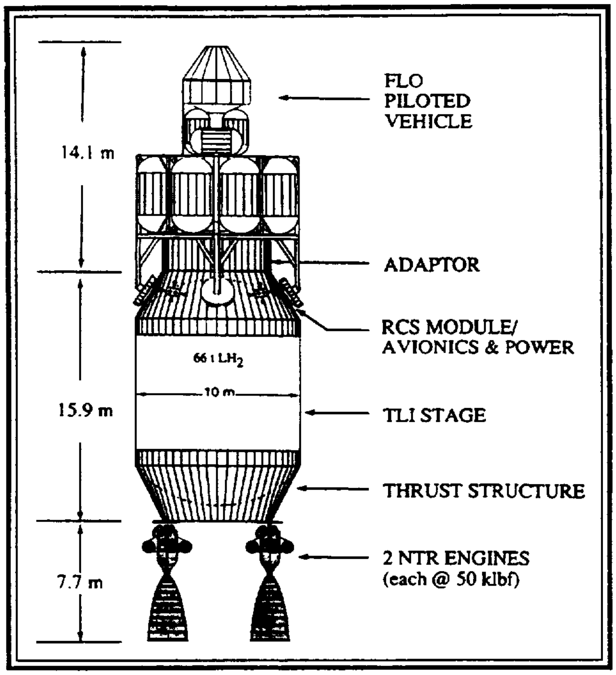


FIGURE 2. Benefits of NTR Propulsion for "First Lunar Outpost".



Expendable FLO TLI Vehicle

Element	Mass (t)	
• TLI Stage	13.30	
• Avionics and Power	1.00	
• Reaction Control	0.46	
• NTR Assemblies		
Engines (2)	10.47	
External Shields (2)	6.00	
• Contingency	3.95	
• Dry Mass		35.17
• LH_2 Propellant	65.48	
• RCS Propellant	1.06	
• Stage Mass		101.73
• FLO Piloted Vehicle	93.00	
• FLO/Stage Adaptor	3.00	
• IMLEO		197.73

FIGURE 3. Vehicle Configuration and Mass Properties for FLO.

required between the PTV and CTV. The third option, the "No MEV/No trans-Earth Injection (TEI) Propellant" mode (also referred to as the "Minimum Piloted Mass" option), uses CTVs to pre-deploy at Mars all cargo including Earth return propellant. The TEI propellant can be transported either in a "tanker" CTV or in a separate "return stage". Both techniques still require a Mars orbit rendezvous between the PTV and CTV, but the latter option would eliminate the need for propellant transfer. NTR vehicle designs have been developed for each of the split/sprint mission modes. The Mars mission ground rules, assumptions, and ΔV budgets used in this study are summarized in Tables 3 and 4, respectively.

Mars Cargo Vehicle

By extending the length of the FLO NTR stage (to ~20 m), upgrading avionics, and increasing fuel cell reactants and reaction control system (RCS) propellants, a single launch Mars cargo vehicle is possible. In the cargo mission scenario, a single trans-Mars injection (TMI) burn lasting ~24.5 minutes is used for Earth departure. Upon reaching Mars, the cargo vehicle performs a 3.5 minute Mars orbit capture (MOC) burn to achieve a 250 x 33,840 km (~24 hour period) elliptical parking orbit. At the appropriate time, the Mars cargo lander performs a de-orbit maneuver and uses a combination of aerobraking, parachutes and terminal descent propulsion to land ~45 t of payload on the Mars surface. Three cargo vehicles would precede the piloted vehicle in the "All-Up" mission mode with a fourth cargo mission (carrying the piloted MEV) required in the "No MEV" mission option. In the "No MEV/No TEI propellant" mode, a "tanker" CTV (functioning as a separate Earth "return stage") is added to support the piloted mission.

The overall configuration and mass properties for the Mars cargo vehicle are shown in Figure 4. The IMLEO is under 201 t and the overall vehicle height is ~43.2 m. The length available for the Mars cargo vehicle is ~44.8 m. This is set by the length of the Saturn V-derived HLLV's first and second stages (~80.2 m) and the height of the Vertical Assembly Building doors (~125 m).

TABLE 3. Mars Mission Ground Rules and Assumptions.

Mission

	Cargo	Tanker	Piloted	
• Payload Outbound	4 x 63.0 t	-	-	MEV
	-	50.3 t	-	TEI Propellant
	-	-	55.8 t	Crew Habitat
• Payload Return	-	55.8 t	-	Crew Habitat
	-	6.8 t	-	MEV Crew Cab
	-	1.0 t	-	Mars Return Samples
• Parking Orbits	407 km	407 km	407 km	Earth Departure (circular)
		250 km x 1 sol		Mars Arrival/Departure
• Perigee Burns	1	1	1-3	Earth Departure
• Crew Size	-	-	6	

Propulsion

• NTR System	
Propellant	Cryogenic Hydrogen
Isp	900 sec (composite)/ 870 sec (graphite)
External Shield Mass	≈ 60 kg/ klbf thrust
Burn Duration	≤ 30 minutes
Flight Performance Reserve	1% of usable propellant
Cool down (effective)	3% of usable propellant
Residual	1.5% of total tank capacity
• RCS System	
Propellant	N_2O_4/MMH
Isp	320 sec

Structure

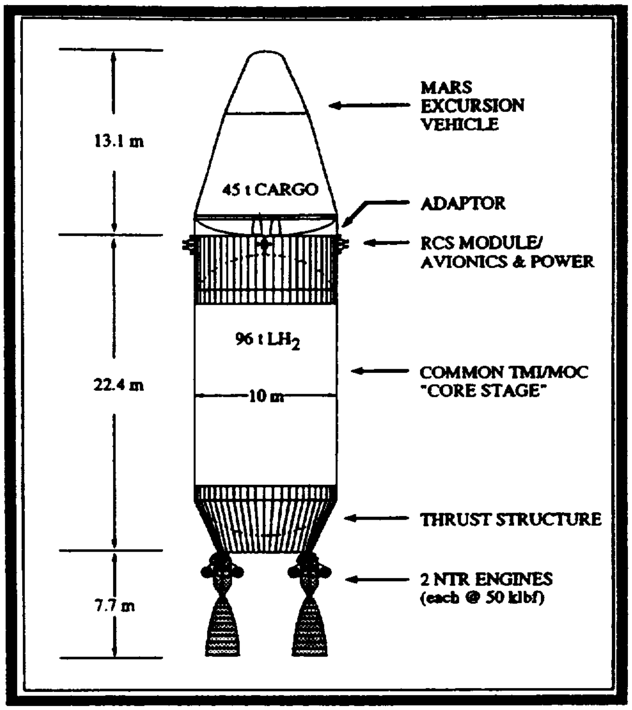
• Tankage	
Material	2219-T87 Al
Diameter	10 m
Geometry	Cylindrical tank with √2/2 domes
• Insulation	
Cargo	2" MLI + micro shield (3.97 kg/m^2)
Piloted & Tanker	
"Core Stage" & "In-line" tanks	4" MLI + micro shield+VCS (7.53 kg/m^2)
TMI "Drop" Tanks	2" MLI + micro shield (3.97 kg/m^2)
• Contingency	
Engine & External Shield	15%
All other dry masses	10%

Boiloff

• Cargo Vehicle	0.769 kg/m^2/month
• Piloted & Tanker Vehicle	
"Core Stage" & "In-line" tanks	0.375 kg/m^2/month
TMI "Drop" Tanks	0.769 kg/m^2/month

Miscellaneous

• Gravity losses modelled for Earth departure only



2007 Mars Cargo Vehicle

Element	Mass (t)	
• Common TMI/MOC "Core Stage"	18.81	
• Stage Avionics & Power	2.00	
• Reaction Control	0.48	
• NTR Assemblies		
Engines (2)	10.47	
External Shields	-	
• Contingency	3.70	
• Dry Mass		35.46
• LH_2 Propellant	95.33	
• RCS Propellant	5.35	
• Stage Mass		136.14
• Mars Excursion Vehicle	63.00	
• MEV/Stage Adaptor	1.70	
• IMLEO		200.85
Total IMLEO (3 vehicles)		602.55

FIGURE 4. Mars Cargo Vehicle and Mass Properties.

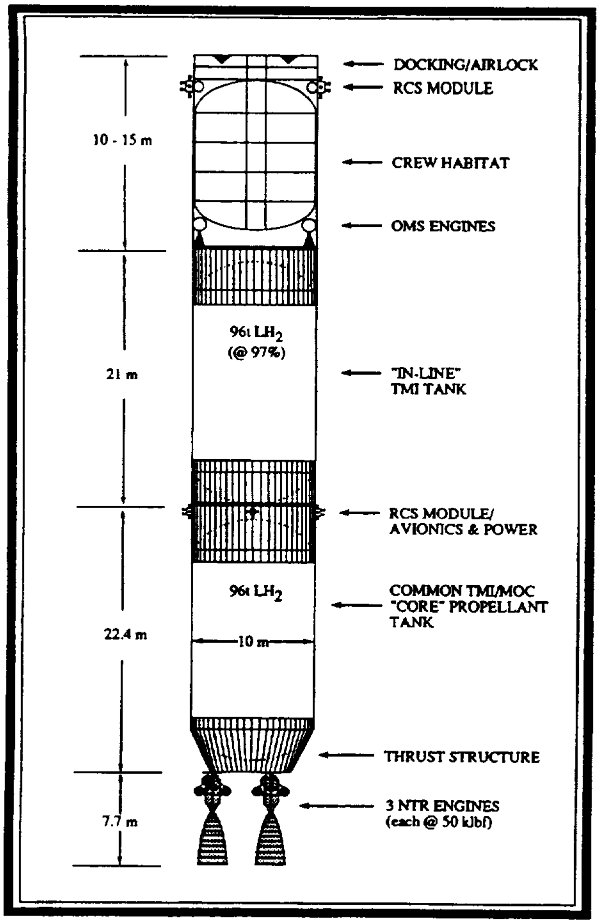
TABLE 4. Mars Cargo and Piloted Mission ΔV Budgets.

Vehicle Mission Mode	Launch Date	Outbound Transit Time (days)	Inbound Transit Time (days)	Total Mission Time (days)	TMI ΔV (km/s)	MOC ΔV (km/s)	TEI ΔV (km/s)	Total ΔV (km/s)
Cargo	2007	343.2	N/A	343.2	3.882	0.831	N/A	4.713
Piloted Outbound	2009	191.4	N/A	721.7	4.431	2.188	N/A	6.619
Tanker Outbound/ Piloted Inbound	2009	320	158.7	915	3.740	0.814	2.601	7.155

Note:
ΔV based on 407 km circular orbit at Earth and 250 x 33840 km elliptical Mars parking orbit.
TMI ΔV includes 100 m/s for plane change
TEI ΔV includes 150 m/s for apsidal alignment

Mars Piloted Vehicle

The 2010 Mars landing mission is one of the most demanding mission opportunities over the ~15 year synodic cycle. Preliminary estimates by LeRC for the "All-Up" mission mode indicate IMLEO requirements approaching 1000 t for a 300 day total transit time (880 day total mission time) "fast-conjunction"-class mission with an ~24 hour elliptical Mars parking orbit. For the present study a total mission transit time (outbound and back) of ~350 days was chosen as the reference (see Table 4). Engine and total thrust levels ranging from 25 to 125 klbf, and



2010 Mars Piloted Vehicle "No MEV/No TEI Propellant Mission"

Element	Mass (t)	
• Crew Habitat System	55.75	
• Common TMI / MOC "Core Stage"	22.09	
• TMI "In-Line" Tank	22.70	
• Stage Avionics & Power	2.00	
• Reaction Control System	1.04	
• NTR Assemblies		
Engines (3)	15.71	
External Shields (3)	9.00	
• Contingency	8.49	
• Vehicle Dry Mass		136.78
• LH_2 Propellant	189.52	
• RCS Propellant	7.63	
• IMLEO		333.93

FIGURE 5. "Outbound" Mars Piloted Vehicle and Mass Properties.

from 100 to 250 klbf, respectively, were also examined. The optimum total thrust level for the more difficult "All-Up" and "No MEV" mission modes was found to be ~150 klbf with two 75 klbf-class engines providing the lowest IMLEO. Three 50 klbf-class engines were chosen as the reference configuration, however, because of the commonality with the FLO lunar transfer stage and the Mars cargo vehicle (both of which use 50 klbf-class engines). The three engine configuration also allows for the possibility of successful mission completion even with the loss of one engine, an option that does not exist with two engines.

Figure 5 shows the overall configuration and mass properties for the outbound Mars piloted vehicle operating in the "No MEV/No TEI propellant" mission mode. The vehicle consists of a "core stage" and "in-line" LH_2 propellant tank (each 10 m in diameter and 20 m in length), and a crew habitat module. The piloted vehicle is assembled at a 407 km circular Earth orbit altitude using two 230 t -class HLLVs. Autonomous rendezvous and docking is assumed between the "core" stage and the combined "in-line" LH_2 tank/crew habitat payloads. A "single burn" Earth departure scenario is baselined with gravity losses on the order of 315 m/s. A "triple perigee" burn scenario reduces gravity losses to ~80 m/s and the piloted vehicle IMLEO by approximately 9 t (from ~334 to 325 t). The "in-line" propellant tank provides ~67% of the usable propellant required for TMI with the remaining 33% being provided by the "core" stage propellant tank. The "single burn" TMI maneuver requires a total burn time by the three 50 klbf NTRs of ~31 minutes.

After an outbound transfer time of ~191 days, the piloted vehicle initiates the MOC burn which lasts for ~9 minutes. Following rendezvous and docking maneuvers between the piloted vehicle and the cargo vehicle transporting the piloted MEV (Figure 6a), the crew descends to the Martian surface to begin a 530 day stay. During this surface exploration period, the "tanker" CTV arrives at Mars and docks with the habitat module on the outbound piloted vehicle (Figure 6b). In the scenario assumed here, the tanker functions as the Earth return stage for the inbound portion of the piloted mission (Figure 6c) with the "spent" outbound piloted stage being jettisoned after hab module transfer. This approach eliminates the need for propellant transfer between the "tanker" CTV and the PTV. When the surface mission is completed, the crew returns to the "reconfigured" piloted vehicle in the ascent portion of the piloted MEV (Figure 6d). Prior to TEI, the MEV ascent stage is jettisoned. The MEV crew cab, however, is retained for later use during Earth entry (Figure 6e). The total "round trip" burn time on the "tanker" CTV's three 50 klbf engines is ~32.5 minutes. Figure 7 shows the overall configuration and mass characteristics for the 2009 "tanker/return stage" Mars cargo vehicle.

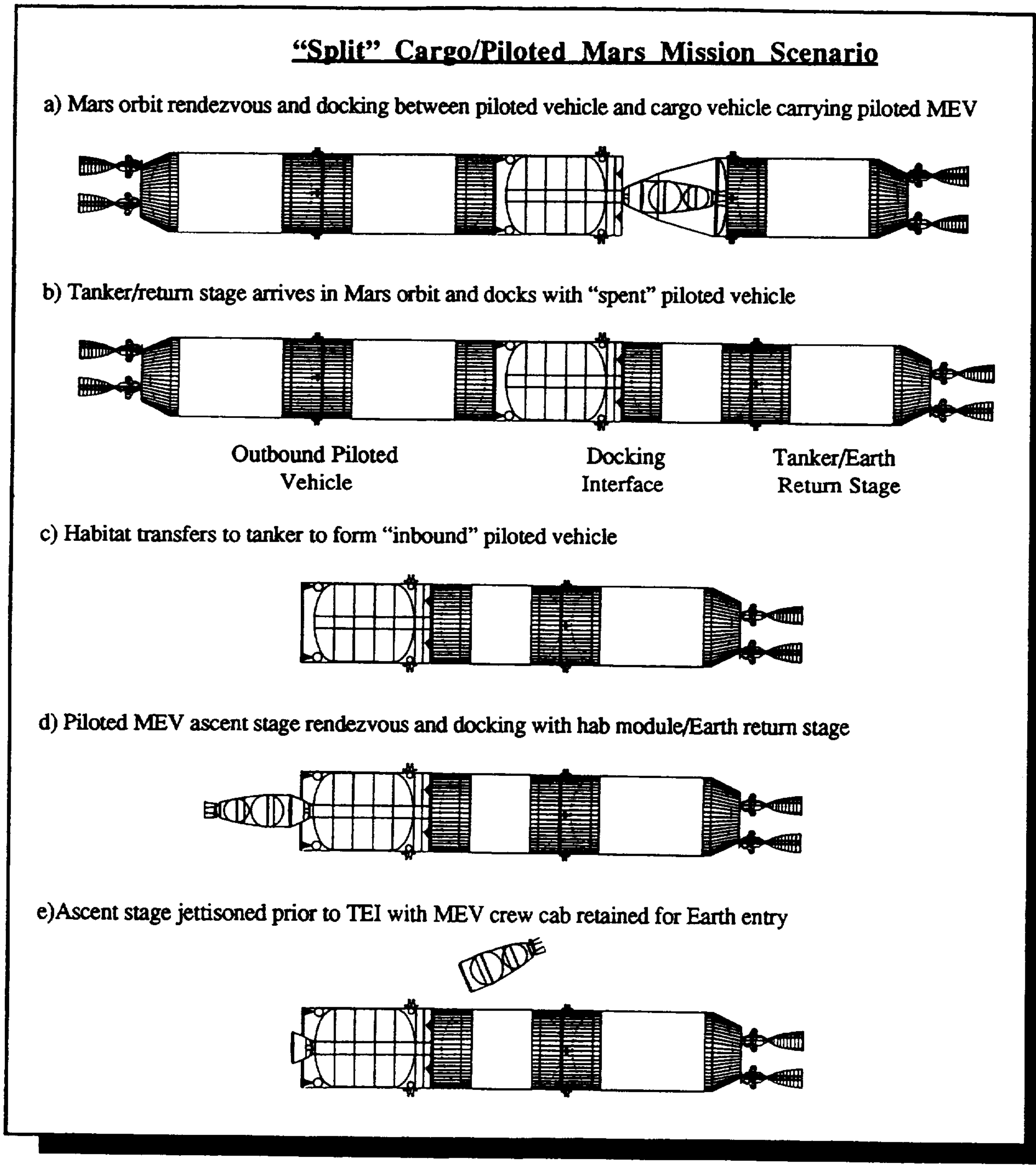
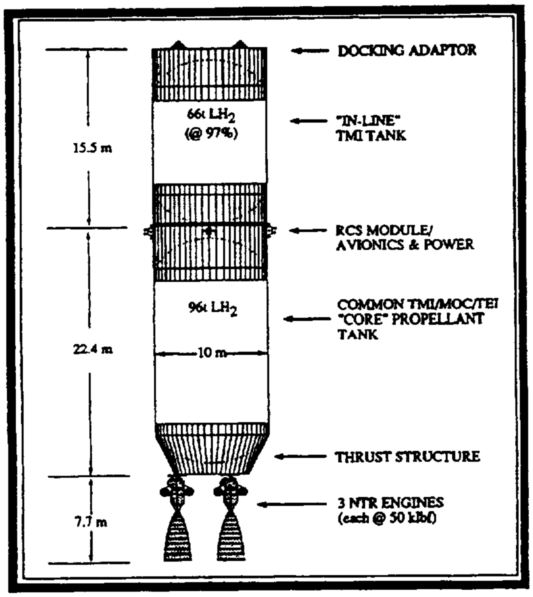


FIGURE 6. Mars Orbital Maneuvers between Cargo, Piloted and Tanker Vehicles.



2009 Mars Tanker Vehicle

Element	Mass (t)	
• Common TMI/MOC/TEI "Core Stage"	22.09	
• TMI "In-Line" Tank	18.30	
• Stage Avionics & Power	2.00	
• Reaction Control	1.04	
• NTR Assemblies		
Engines (3)	15.71	
External Shields	9.00	
• Contingency	8.05	
• Dry Mass		76.19
• LH_2 Propellant	160.34	
• RCS Propellant	6.72	
• IMLEO		243.25

FIGURE 7. Mars "Tanker" Vehicle and Mass Properties

The relative size of the cargo and piloted vehicles supporting the 2010 Mars mission are shown in Figure 8 along with the FLO NTR TLI stage for comparison. The piloted vehicle for the "All-Up" split mission mode has the largest IMLEO at ~760 t and is the most demanding in terms of the number of HLLVs and time required for orbital assembly (5 launches over ~10 months assuming 60 day launch centers). The three TMI "drop" tanks are attached to a pre-integrated truss/LH_2 feed system which also connects the basic spacecraft to the crew habitat module and MEV.

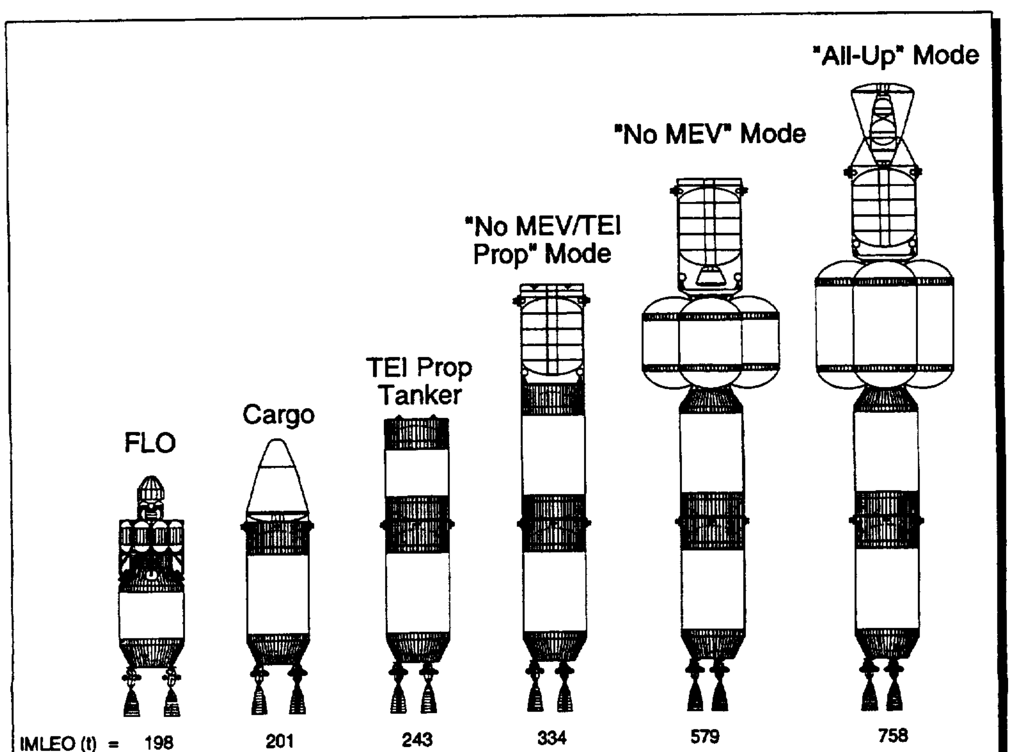


FIGURE 8. Relative Size of Lunar/Mars Vehicle Configurational Options.

With the "No MEV" mission mode, the IMLEO can be reduced by ~180 t. The greatest reduction in piloted vehicle mass occurs, however, with the "No MEV/No TEI Propellant" mission mode. With this scenario piloted vehicles on the order of 300 to 350 t can be assembled in LEO with two launches of a 150 to 200 t- class HLLV. Figure 9 summarizes the key components of the modular NTR approach discussed in this paper.

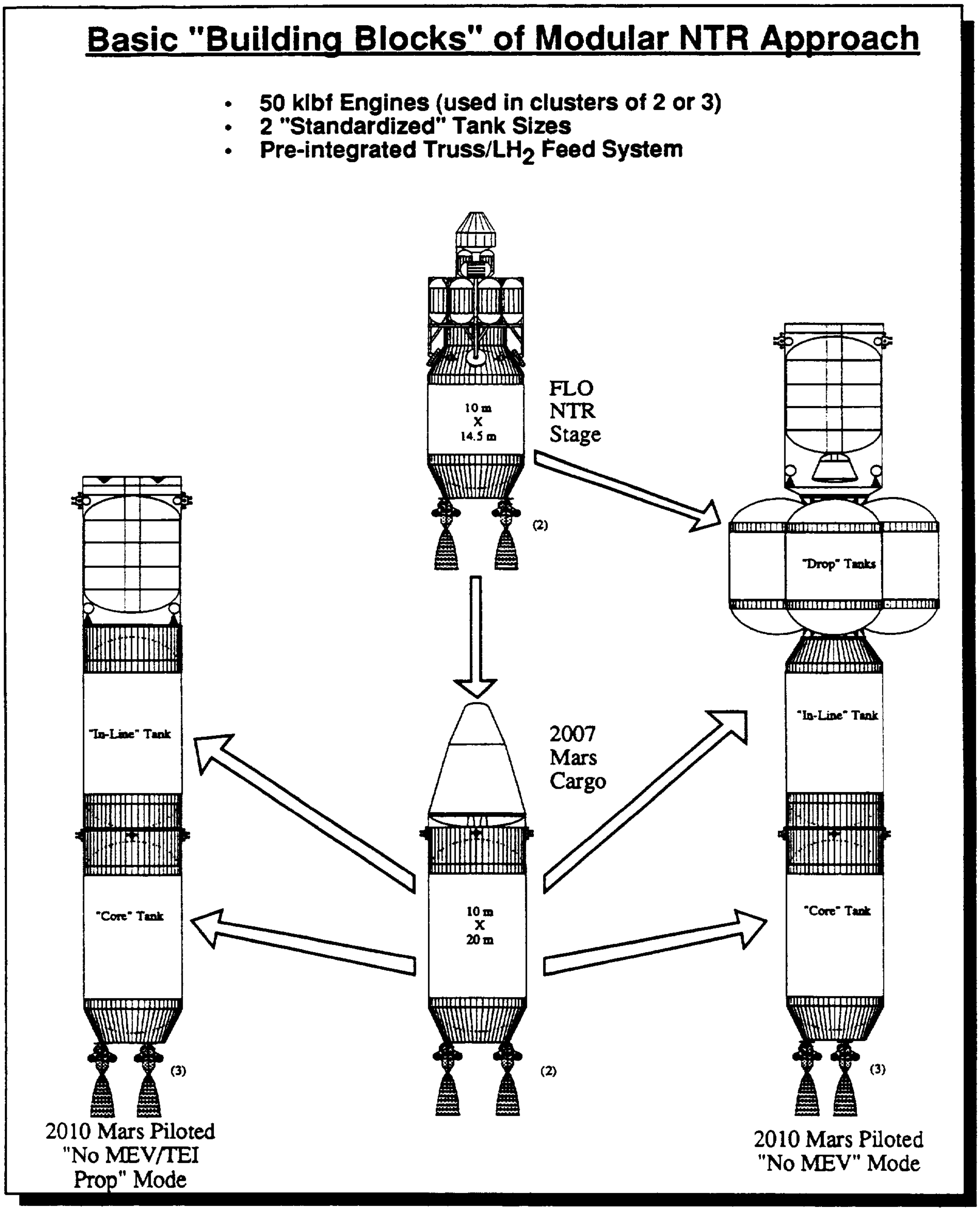


FIGURE 9. Key Components of Modular, NTR-Based Lunar/Mars Transportation System.

SUMMARY AND CONCLUSIONS

The rationale and benefits of developing and implementing an evolutionary lunar-to-Mars STS based on modular NTR engine and stage components are presented. Key components of this modular approach are described and consist of (1) a 50 klbf NERVA-derived engine used in clusters of 2 or 3; (2) two "standardized" tank sizes developed for the First Lunar Outpost and Mars cargo vehicle applications; and (3) for larger piloted vehicle configurations, a pre-integrated truss/propellant feed system used for transferring LH_2 from the TMI drop tanks into the "in-line" tank. By using these components in a "building block" fashion a variety of single and multi-engine lunar and Mars vehicles can be configured to satisfy particular mission requirements.

With its factor of two advantage in I_{sp} over chemical propulsion and its high thrust-to-weight ratio, the NTR is ideally suited to performing both piloted and cargo, lunar and Mars missions. The modular NTR approach can form the basis for an efficient space transportation system, satisfying the needs of all these options. What will be required for its realization is a "new design philosophy" -- away from customized and mission specific transportation system concepts to a "faster, better, cheaper" concept utilizing a single, common system design able to handle the needs of a wide spectrum of lunar and Mars missions.

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References

Borowski, S. K. (1991) "The Rationale/Benefits of Nuclear Thermal Rocket Propulsion for NASA's Lunar Space Transportation System," AIAA-91-2052, presented at 27th Joint Propulsion Conference, Sacramento, CA, 24-26 June 1991.

Borowski, S. K., J. S Clark, R. J. Sefcik, R. R. Corban and S. W. Alexander (1992) "An Accelerated Development, Reduced Cost Approach to Lunar/Mars Exploration Using a Modular NTR-Based Space Transportation System," IAF-92-0574, presented at 43rd Congress of the International Astronautical Federation, Washington, DC, August 28 - September 5, 1992.

EXPO (1992a) *Analysis of the Synthesis Group Architectures: Summary & Recommendations*, XE-92-004, NASA Exploration Program Office, Houston, TX.

EXPO (1992b) *Analysis of the Synthesis Group's "Moon to Stay & Mars Exploration" Architecture*, XE-92-001, NASA Exploration Program Office, Houston, TX.

Joosten, B. K., B. G. Drake, D. B. Weaver, and J. K. Soldner (1991) "Mission Design Strategies for the Human Exploration of Mars," IAF-91-336, presented at 42nd Congress of the International Astronautical Federation, Montreal, Canada, 5-11 October 1991.

Koenig, D. R. (1986) *Experience Gained from the Space Nuclear Rocket Program (Rover)*, LA-10062-H, Los Alamos National Laboratory, Los Alamos, NM.

NASA (1989) *Report of the 90-Day Study on Human Exploration of the Moon and Mars*, National Aeronautics and Space Administration, Washington, DC.

Synthesis Group (1991) *America at the Threshold - America's Space Exploration Initiative*, Report of the Synthesis Group, U.S. Government Printing Office, Washington, DC.

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13. ABSTRACT ***(Maximum 200 words)***

Integrated systems and missions studies are presented for an evolutionary lunar-to-Mars space transportation system (STS) based on nuclear thermal rocket (NTR) technology. A "standardized" set of engine and stage components are identified and used in a "building block" fashion to configure a variety of piloted and cargo, lunar and Mars vehicles. The reference NTR characteristics include a thrust of 50 thousand pounds force (klbf), specific impulse (I_{sp}) of 900 seconds, and an engine thrust-to-weight ratio of 4.3. For the National Aeronautics and Space Administration's (NASA) First Lunar Outpost (FLO) mission, and expendable NTR stage powered by two such engines can deliver ~96 metric tonnes (t) to trans-lunar injection (TLI) conditions for an initial mass in low Earth orbit (IMLEO) of ~198 t compared to 250 t for a cryogenic chemical system. The stage liquid hydrogen (LH_2) tank has a diameter, length, and capacity of 10 m, 14.5 m and 66 t, respectively. By extending the stage length and LH_2 capacity to ~20 m and 96 t, a single launch Mars cargo vehicle could deliver to an elliptical Mars parking orbit a 63 t Mars excursion vehicle (MEV) with a 45 t surface payload. Three 50 klbf engines and the two standardized LH_2 tanks developed for the lunar and Mars cargo vehicles are used to configure the vehicles supporting piloted Mars missions as early as 2010. The "modular" NTR vehicle approach forms the basis for an efficient STS able to handle the needs of a wide spectrum of lunar and Mars missions.

14. SUBJECT TERMS

Nuclear thermal rocket; NTR; First lunar outpost; FLO; Rover, NERVA; Modular; Space transportation; Moon; Mars

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